

3. INTRODUCTION TO McDONNELL DOUGLAS PROGRAM

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The McDonnell Douglas Corporation part of the NASA treated-nacelle program was performed for the Langley Research Center under Contract NAS 1-7130 in five phases: (1) nacelle design studies and duct lining investigations, (2) ground static tests of noise suppressor configurations, (3) flight tests of a selected nacelle modification design, (4) studies of economic implications of retrofit, and (5) an evaluation of human response to the flyover noise of the modified nacelles.

Results of the flight test program are summarized by David K. Gordon in paper no. 4 and Alan H. Marsh in paper no. 5. Performance and operational changes are described by Gordon and the effects of the treated nacelles on flyover noise are described by Marsh. Economic implications of modifying the existing short-duct nacelles of DC-8 airplanes to the treated nacelle configuration are discussed in paper no. 6 by H. D. Whallon. A status report of the investigation of human response to the flyover noise of the modified nacelles is presented in paper no. 12 by Lawrence E. Langdon and Richard F. Gabriel.

It is the purpose of this introductory paper to describe the nacelle design selected for the flight test program and to summarize the background work that resulted in the selection of the design.

DESCRIPTION OF SELECTED NACELLE DESIGN

A photograph of one of the four nacelles built for the flight test program is shown as figure 1. The inlet contained a total of 64 square feet of acoustically absorptive linings located on the inlet duct inner surface, the center body, and on the inner and outer surfaces of a concentric ring vane. The ring vane was supported by struts located in the vertical and horizontal planes. The design of the struts provided for passages through which compressor bleed air could be ducted for anti-icing of the leading edges of the struts and the ring vane. However, the experimental flight nacelles were not equipped with an operable anti-icing system since such a system was unnecessary to evaluate the acoustic and aerodynamic effects of the acoustically treated inlet.

The fan discharge ducts were 24 inches longer than those of the existing short-duct nacelles of the DC-8 series 50 and model 61 airplanes and contained a total of approximately 70 square feet of acoustically absorptive duct linings. The nacelle overall length and cross section and the primary nozzle and thrust reverser were not altered by the

modification. External nacelle contours were changed slightly from the inlet lip aft to the primary thrust reverser. The changes were needed to accommodate the revised design for the fan discharge ducts and nozzles. No change was required in the contours at the nacelle-pylon junction or in any of the mechanical or subsystem interfaces at this junction.

The acoustic treatment used in the inlets and fan discharge ducts is illustrated in figure 2. The porous facing sheet, which replaces the aluminum skins in the existing inlet and discharge ducts, is in grazing contact with the duct aerodynamic flow. The facing sheets were made of sintered fine stainless-steel fibers. These sheets, together with an impervious solid backing sheet, were bonded to a honeycomb core made from phenolic-resin-coated fiber-glass cloth. The bonding agent was an aluminum-filled modified epoxy adhesive. The drainage slots prevent the accumulation of water or other nacelle fluids within the honeycomb cells.

SELECTION OF TREATED-NACELLE DESIGN

The design of the modified nacelle was selected on the basis of the work of the first two phases of the program. An initial step in the development of the design was the definition of the suppression requirements of the fan inlet and discharge ducts as shown in figure 3. Previous work had shown that the maximum perceived noise level radiated from the JT3D inlet is approximately 3 PNdB less than that radiated from the fan exit. Therefore, to achieve an overall reduction of 10 PNdB, the perceived noise levels from the inlet and fan exit ducts must be reduced by 7 PNdB and 10 PNdB, respectively.

The meager information on acoustical duct lining absorptivity available at the beginning of the program was reviewed to develop a tentative design chart for estimating the amount and location of lining materials required to accomplish the required noise reductions. This estimate indicated that 48-inch-long discharge ducts, as shown in figure 4, would satisfy the requirement if acoustical linings were provided on all inner duct walls and on both sides of four longitudinal splitters that divide each discharge duct into five channels. The design required a new fan thrust reverser located 24 inches farther downstream than the existing reversers. A new target-type reverser design consisting of a single pivoting bucket on each side of the nacelle was evolved to fit within the reduced space between the engine casing and the nacelle skin in the farther downstream location. (See fig. 4.) As for the anti-icing system, a functioning fan thrust reverser was not needed to achieve the program goals and was therefore not provided in the flight test nacelles.

Another approach to the reduction of noise radiated from the fan discharge ducts was evaluated in the design studies phase of the program. This approach, as illustrated

in figure 5, was intended to provide the required acoustical lining area with minimum changes to existing nacelle equipment. The treated fan discharge ducts had the same length and nozzle shape as the existing production discharge ducts. The supplementary panels augmented the treated area that could be provided within the 24-inch-long ducts, since it was estimated that the treated area within the ducts would be insufficient to achieve the required noise reduction. The panels would normally be stowed flush on the cowl sides forward of the fan exit nozzles. When noise suppression is required, they would be translated rearward to the position shown in figure 5. Estimates of the increase in direct operating costs due to the two designs indicated lower costs for the 48-inch duct design. Furthermore, the supplementary panels would tend to degrade safety, since failure of one of them to retract would make reverse thrust unavailable from the affected nacelle. For these reasons, the 48-inch duct design was selected for further investigation in the succeeding ground test program.

The selected ring-vane inlet design, which is shown in figure 6, was a derivative of one of a number of inlet configurations investigated in the nacelle design studies phase. Two of the study configurations were investigated in the ground test program.

One of the configurations, which is shown in figure 7, was acoustically identical to the selected design except that it contained a second concentric ring vane located between the ring vane shown in figure 6 and the center body. In the horizontal plane, the internal shape and location of the inlet duct, the center body, and the outer ring vane of the two designs (figs. 6 and 7) were identical downstream of the throat of the inlet. The ring vanes provided additional acoustically absorptive surface area without elongation of the inlet. They also reduced the spacing between treated surfaces, which is believed to improve the absorptivity of the acoustical materials. The second configuration was a basically different type illustrated in figure 8. Additional acoustically treated area was provided in the lightbulb inlet by elongation of the inlet and enlargement of the center body. The larger center-body diameter, in addition to providing more acoustically treated area, was thought to offer the potential of some additional noise reduction through partially obstructing the direct path of the noise propagating forward from the fan inlet.

Figures 7 and 8 illustrate the two-ring and lightbulb inlet designs as they were tested on an outdoor JT3D engine test stand. External inlet contours were simulated only as far aft as was required for satisfactory flow over the inlet lip, and the inlets were built axisymmetrically in the interests of test economy.

The tests indicated that the lightbulb configuration achieved slightly more noise reduction than the two-ring inlet. Also, tests with the inner ring removed from the two-ring inlet indicated that the required noise reduction was achieved with only the outer ring installed. Since this single-ring configuration met the noise reduction requirement at the least estimated cost in weight, drag, and thrust loss, it was selected for the flight test program.

The full-scale tests of the treated-inlet configuration were made with the existing production short fan discharge ducts installed and with a large enclosure completely surrounding the engine aft of the treated inlet. The function of the enclosure was to suppress the fan exit noise and thereby permit evaluation of the noise reduction achieved individually by the treated inlets. The inner surfaces of the three walls and ceiling of the enclosure were covered with 4-inch-thick fiber-glass batts. Similarly, a ground test model of the treated 48-inch fan discharge duct configuration was tested with a large enclosure fitted to the inlet. Details of the enclosures and the test techniques used are presented in reference 1. Sound pressure levels were measured along an arc of 150-foot radius centered on the primary exhaust nozzle. Estimates of flyover noise were calculated by a technique that utilized these ground test measurements. These estimates indicated that the treated single-ring inlet and the treated 48-inch discharge ducts would achieve landing noise reductions of 8 and 11 PNdB, respectively, which are slightly in excess of the requirements of 7 and 10 PNdB. A final test of the inlet and exit ducts was made with these components installed simultaneously and the suppressor enclosures removed. The results indicated a landing noise reduction of 11 PNdB, in confirmation of the results obtained with the components tested individually.

An explanation of weight changes that would result from converting existing nacelles to treated nacelles will help in understanding the performance and economic effects discussed by Gordon (paper no. 4) and Whallon (paper no. 6).

Five major new components are required to convert existing nacelles: a treated inlet, treated fan discharge ducts (left and right), and fan thrust reversers (left and right). As indicated in figure 9, the new acoustically treated inlet and exit ducts would weigh a total of 370 pounds more per nacelle than the existing components they replace. The new target-type thrust reversers, however, would weigh 287 pounds less than the existing cascade type they replace. The weight of all other additional new nacelle components would approximately equal the weight of the components they replaced. The net weight change due to the modification would therefore amount to 83 pounds per nacelle or 332 pounds per airplane. The reduction in fan thrust reverser weight is made possible by the use of target-type thrust reversers rather than the heavier cascade-type reversers now in service. Although reverse-thrust levels of target-type reversers are somewhat less than that of cascade types, thrust reverser development programs subsequent to the design of DC-8 short-duct nacelles have shown that satisfactory levels may be achieved through proper design of the target-type reverser.

The total scope of the nacelle modification may be indicated by relating the weight of the new components to the total nacelle weight. The weight of all nacelle components (excluding the engines) presently in service totals 10 188 pounds per airplane. Of these components, 5156 pounds would be removed and replaced by 5488 pounds of the new

components. Measured in this manner, retrofit of acoustically treated ducts would affect approximately half of the nacelle components on an airplane.

CONCLUDING REMARKS

The present program dealt with the application of acoustic duct lining technology to DC-8 airplanes equipped with short-duct nacelles, that is, to the series 50 and model 61 airplanes. Although the principles used in developing the present design are believed to be generally applicable to other turbofan-engine installations, it must be remembered that the acoustic, performance, operational, and economic data discussed in the McDonnell Douglas papers apply strictly to the specific airplane models studied.

The existing short-duct design was committed to production engineering in November 1959. Advancements in nacelle mechanical and aerodynamic design subsequent to that time were applied to the acoustically treated nacelle design developed in this program. The reduced weight of the fan thrust reversers for the acoustically treated nacelle is an example. In more recently designed turbofan nacelles, such as those of the DC-8 models 62 and 63 airplanes, these advancements have already largely been applied and, therefore, cannot offset to any significant extent the added weight and internal aerodynamic friction due to retroactive installation of acoustical lining materials. Separate studies would be required to define the design and the acoustic, performance, and economic effects of applying duct lining technology to the nacelles of these airplanes or to the nacelles of airplanes powered by other engines.

REFERENCE

1. Marsh, Alan H.; Zwieback, E. L.; and Thompson, J. D.: Ground-Runup Tests of Acoustically Treated Inlets and Fan Ducts. Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft, NASA SP-189, 1968, pp. 131-162.

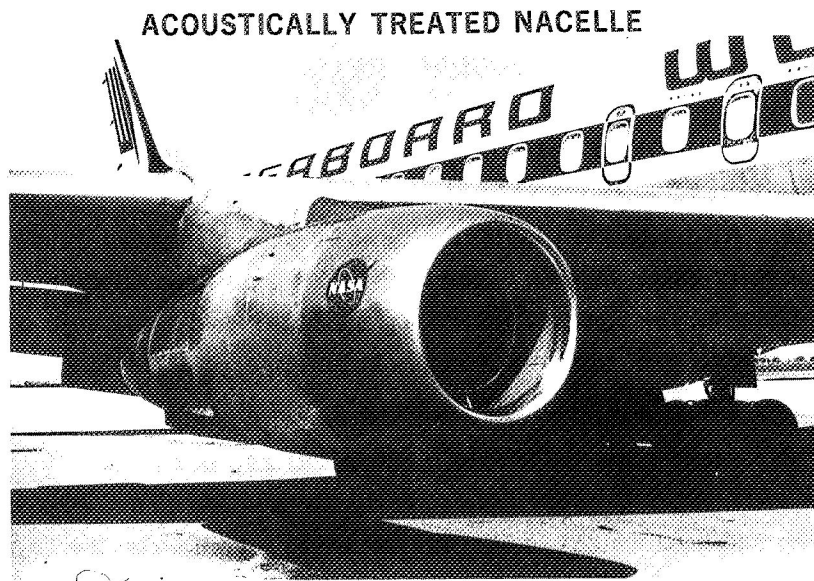


Figure 1

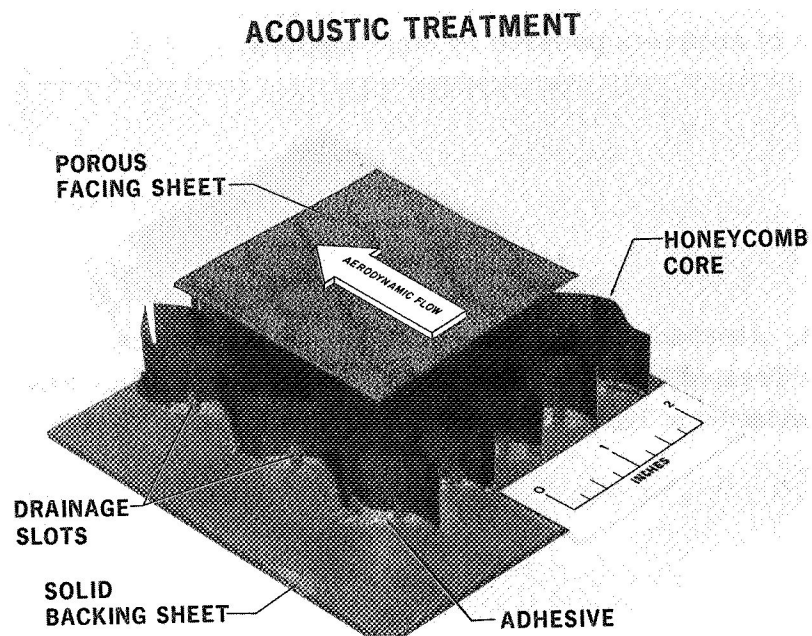


Figure 2

**NOISE-REDUCTION GOALS
LANDING APPROACH POWER**

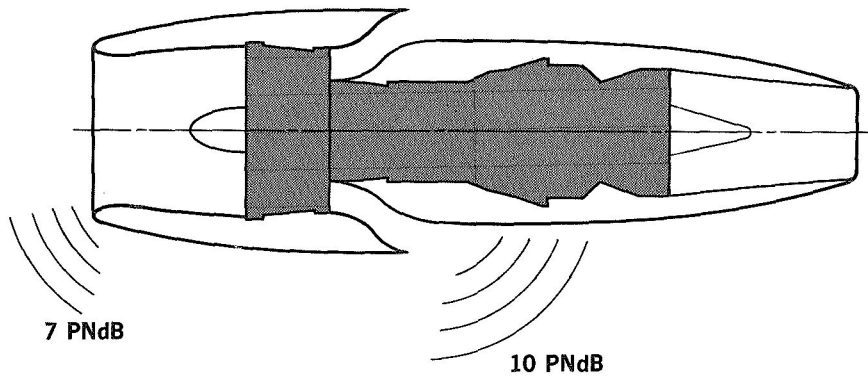


Figure 3

48-INCH TREATED FAN DISCHARGE DUCTS

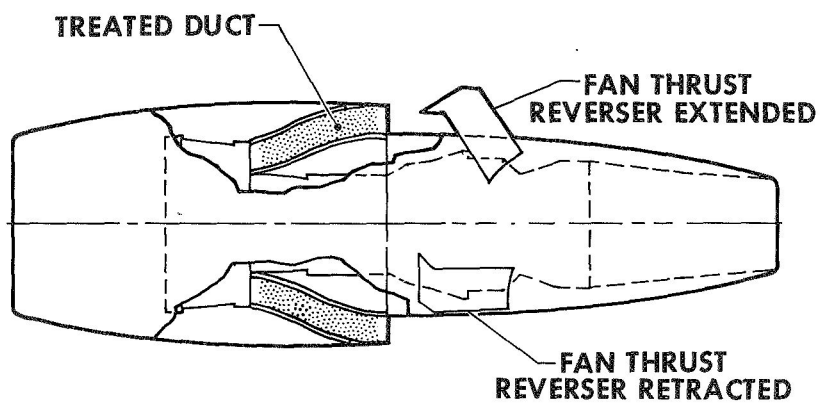


Figure 4

24-INCH TREATED FAN DISCHARGE DUCTS WITH SUPPLEMENTARY PANELS

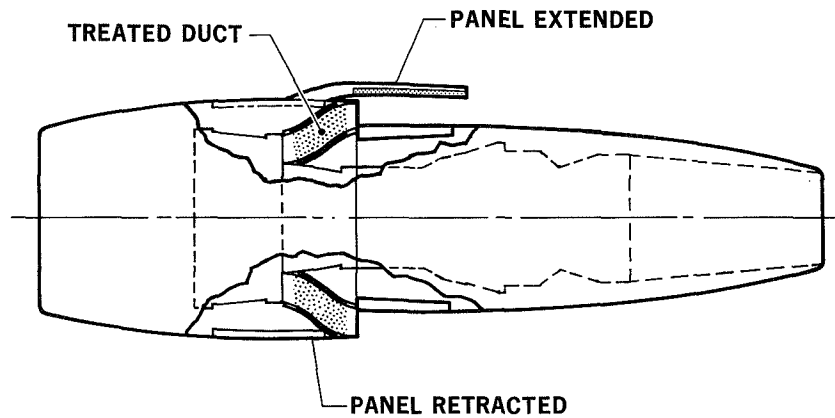


Figure 5

TREATED RING-VANE INLET

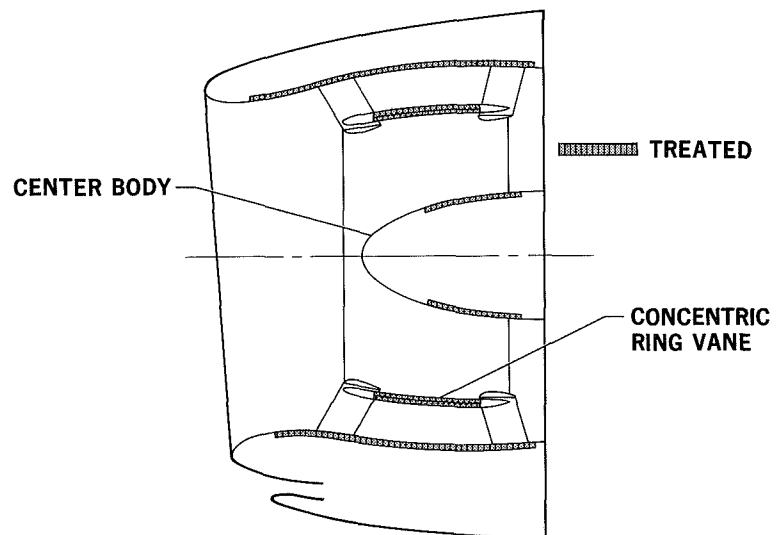


Figure 6

TREATED TWO-RING INLET

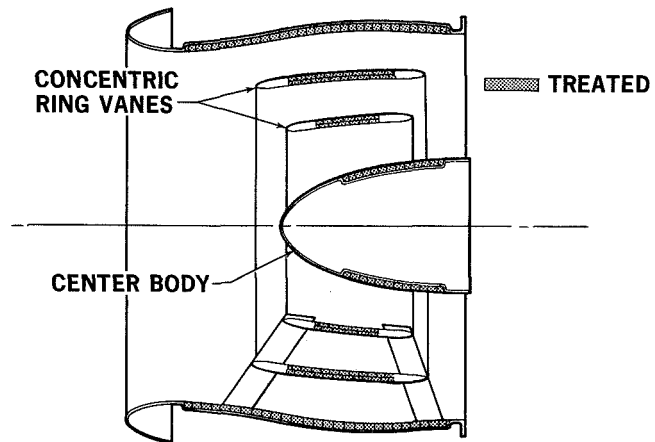


Figure 7

TREATED LIGHTBULB INLET

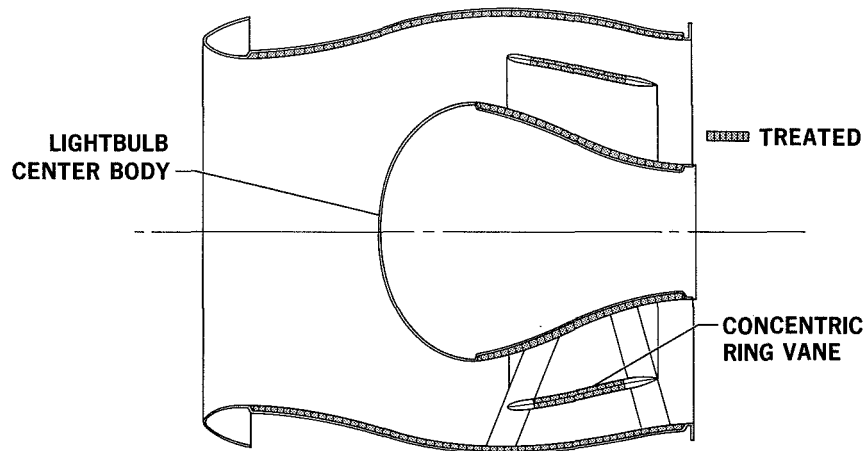


Figure 8

WEIGHT CHANGES

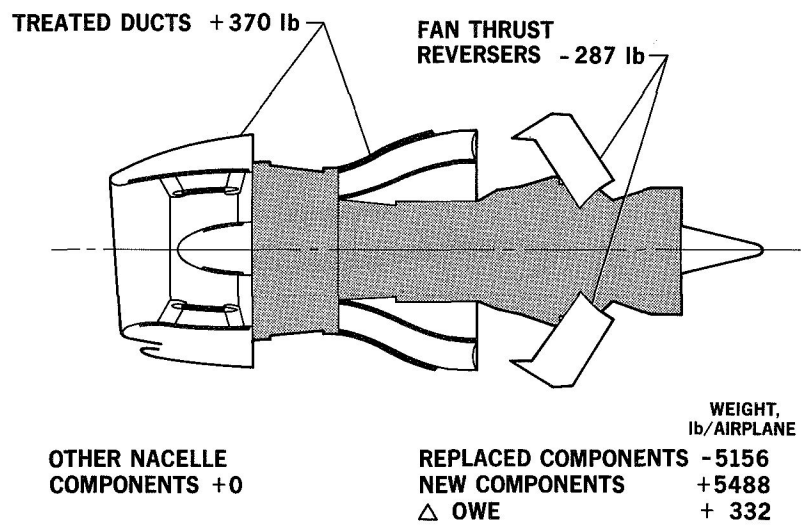


Figure 9